UNDERSTANDING THE MECHANICS OF EARTHQUAKE-INDUCED FLOW LIQUEFACTION: FROM OBSERVATIONS TO PREDICTIONS

Gabriele Chiaro
University of Canterbury, Christchurch, New Zealand
gabriele.chiaro@canterbury.ac.nz

1.0 LIQUEFACTION EFFECTS CHALLENGE: 1 – DEVELOPMENT AND EFFECTS OF LIQUEFACTION-INDUCED FLOW SLIDES THAT ARE GOVERNED BY THE UNDRAINED RESIDUAL SHEAR STRENGTH OF LIQUEFIED SOIL

Recent major seismic events in New Zealand and Japan have shown that a significant portion of earthquake-induced damage to the natural and built environment is related to ground failure associated with soil liquefaction, a phenomenon that mostly occurs in saturated loose sandy soils during earthquakes. The catastrophic effects of liquefaction are most evident in sloped ground, where the liquefaction-induced total loss of soil shear strength and stiffness results in very large horizontal ground deformation (flow liquefaction). While the consequences of such flow liquefaction have been well documented, there is still a lack of knowledge as to the mechanics of earthquake-induced flow liquefaction due to the insufficient understanding of the combined effects of key factors such as slope ground conditions, earthquake characteristics, confining stress level, soil density, fines content, soil structure and fabric etc. – which limits the ability to foresee susceptible soils in advance and thus potentially catastrophic failures occurring.

2.4 KEY CHALLENGES TO DEVELOPING BETTER EVALUATION PROCEDURES

Spanning from purely theoretical standpoint to practical applications, there is a particular interest to enhance understanding of the effects of static shear (i.e. slope inclination) on the failure mechanisms (i.e. failure induced by liquefaction and/or brought about a large deformation extent) of sand subjected to undrained cyclic shear loading.

In an attempt to address this issue, the Author performed a preliminary series of undrained cyclic torsional simple shear tests on saturated Toyoura sand specimens under various combinations of static and cyclic shear stresses (Chiaro et al., 2012). This was possible because of the use of an innovative large-strain torsional shear apparatus developed at the University of Tokyo (Kiyota et al., 2008). Compared with conventional triaxial and simple shear devices, this apparatus is capable of realistically simulating the large deformation behavior that liquefied soil exhibits during earthquakes. Through this preliminary study a more rational and accurate evaluation of liquefaction potential of sandy soils in sloped ground was obtained and a method for the assessment of earthquake-induced flow liquefaction was developed (Chiaro et al. 2015, 2016).

It is known that the resistance to liquefaction of sands depends on the soil properties as well as on the stress conditions such as confining pressure, cyclic shear stress and initial static shear stress. In order to take the above factors into account, the proposed predictive method (Fig. 1) is defined by means of three fundamental parameters namely: (i) static stress ratio, SSR (= τ_{static}/p_0'), which corresponds to the driving shear force induced by the inclination of slopes; (ii) cyclic stress ratio, CSR (= τ_{cyclic}/p_0'), that represents the inertial force exerted by earthquakes; and (iii) undrained shear strength ratio (USS = τ_{und}/p_0'), where τ_{und} is expected to vary depending on initial relative density (D_r) and effective mean principal stress level (p_0'), among other factors. Moreover, by plotting the experimental data (Chiaro et al., 2012) in terms of η_{max} (= (SSR+CSR)/USS) vs. η_{min} (= (SSR-CSR)/USS), a four-zone graph with well-defined boundary conditions was established. Each zone corresponds to a distinct liquefaction/failure behaviors observed in the laboratory (Chiaro et al., 2012, 2015), namely *flow liquefaction (severe liquefaction zone)*; *cyclic liquefaction (moderate liquefaction zone)*; *failure induced by accumulation of large plastic deformation (shear failure zone); and no failure and no* *liquefaction (safe zone)*

Using the proposed predictive method, the liquefaction-induced failure of a very gentle sloped ground that occurred in Ebigase (Japan) during the 1964 Niigata Earthquake (Mw = 7.5 and a_{max} = 0.16g) was carefully evaluated (Chiaro et al., 2016). Similarly to field observation, predictions confirmed that given the sloped ground conditions, under such strong earthquake, severe liquefaction could happen only within the intermediate loose sandy soil layer, approximately at a depth in-between 3.5 m and 6.5 m below the ground surface. On the other hand, for the denser soil elements, liquefaction could not be triggered by the earthquake.

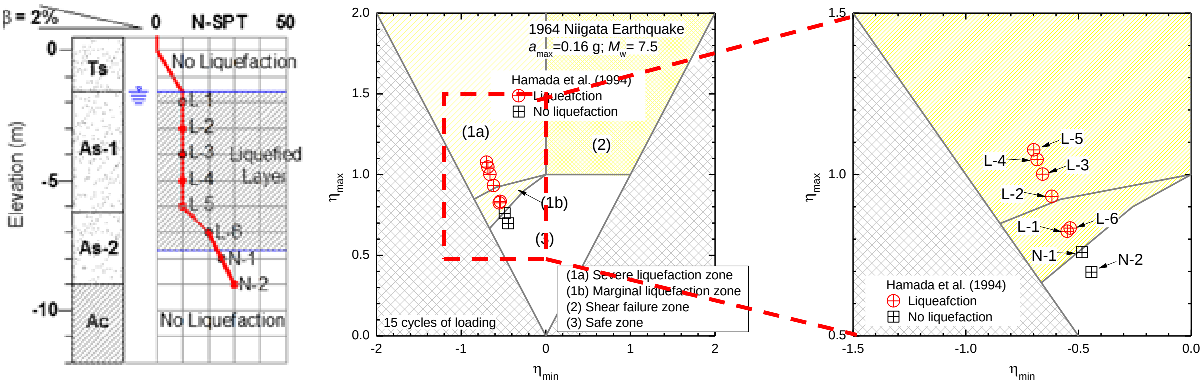

Figure 1. Comparison between observed and predicted failure behaviors of a very gentle slope in Ebigase during the 1964 Niigata Earthquake (Chiaro et al., 2016)

Note that this study was conducted on an idealized sand (i.e. Toyoura sand), and thus the obtained findings are not exhaustive. Moreover, the predictive method is not always directly applicable to all types of liquefiable sandy soil, which have different fines content and structure/fabric compared to that of an idealized clean sand. Accordingly, further comprehensive investigations on fines-containing sands are now planned to supplement past study done by the Author and yield new insights on the fundamental mechanics of earthquake-induced flow liquefaction of sandy soils not previously possible.

3.0 ACKNOWLEDGEMENTS

This abstract is based on research funded by Japanese Government (Monbukagakusho: MEXT) Scholarship and Japanese Society for the Promotion of Science Research Fellowship (JSPS Grant – P14056).

4.0 REFERENCES

Chiaro G., Koseki J. & Sato T. (2012). Effects of initial static shear on liquefaction and large deformation properties of loose saturated Toyoura sand in undrained cyclic torsional shear tests. Soils and Foundations, 52(3): 498-510.

Chiaro G., Koseki J. & Kiyota T. (2015). New insights into the failure mechanisms of liquefiable sandy sloped ground during earthquakes. In: Proc. of the 6th International Conference on Earthquake Geotechnical Engineering, Nov. 1-4, Christchurch, New Zealand, CD-ROM, pp.8.

Chiaro G., Koseki J. & Kiyota T. (2016). An investigation on the liquefaction-induced sloped ground failure during the 1964 Niigata Earthquake. Geomechanics and Geoengineering: Geotechnical Hazards from Large Earthquakes and Heavy Rainfalls, Springer, 134-143.

Kiyota, T., Sato, T., Koseki, J. & Mohammad, A. (2008). Behavior of liquefied sands under extremely large strain levels in cyclic torsional shear tests. Soils and Foundations, 48 (5): 727-739.